DØ Measurement
of
The Dijet Azimuthal Decorrelations

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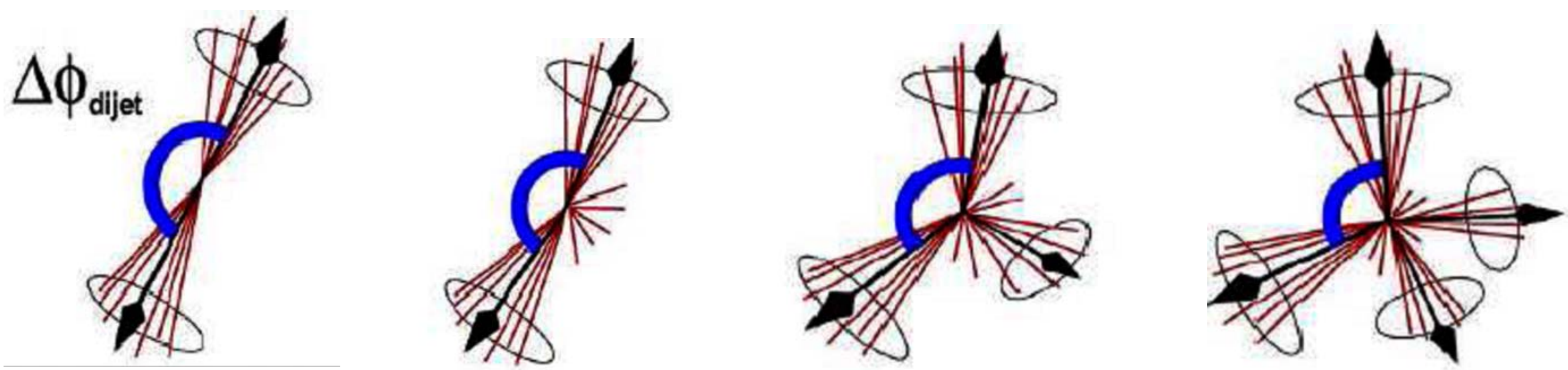
Outline

- Motivation and the $\Delta\Phi$ observable
- Experimental results
- Fixed-order PQCD description: LO and NLO
- Tuning Parton-Shower Monte Carlo's: Pythia and Herwig
- Testing ME-PS matching: Alpgen and Sherpa
- Conclusions

What is $\Delta\Phi$? Why is $\Delta\Phi$ of interest?

- $\Delta\Phi$ is the azimuthal opening angle between the two leading jets
- $\Delta\Phi$ distribution is sensitive to a wide spectrum of QCD radiation effects
  - ➔ Back-to-back production of two jets gives $\Delta\Phi = \pi$
  - ➔ Soft radiation: $\Delta\Phi \sim \pi$
  - ➔ Hard radiation: $\Delta\Phi < \pi$
  - ➔ At least 4 jet configurations for $\Delta\Phi < 2\pi/3$ (3-jet "Mercedes")
- Examine transition between soft and hard physics based on a single observable
- Testing ground for matching procedures that combine MC samples with different jet multiplicities



Experimental Aspects

- Observable: ΔΦ distribution between the two leading jets normalized by the integrated dijet cross section

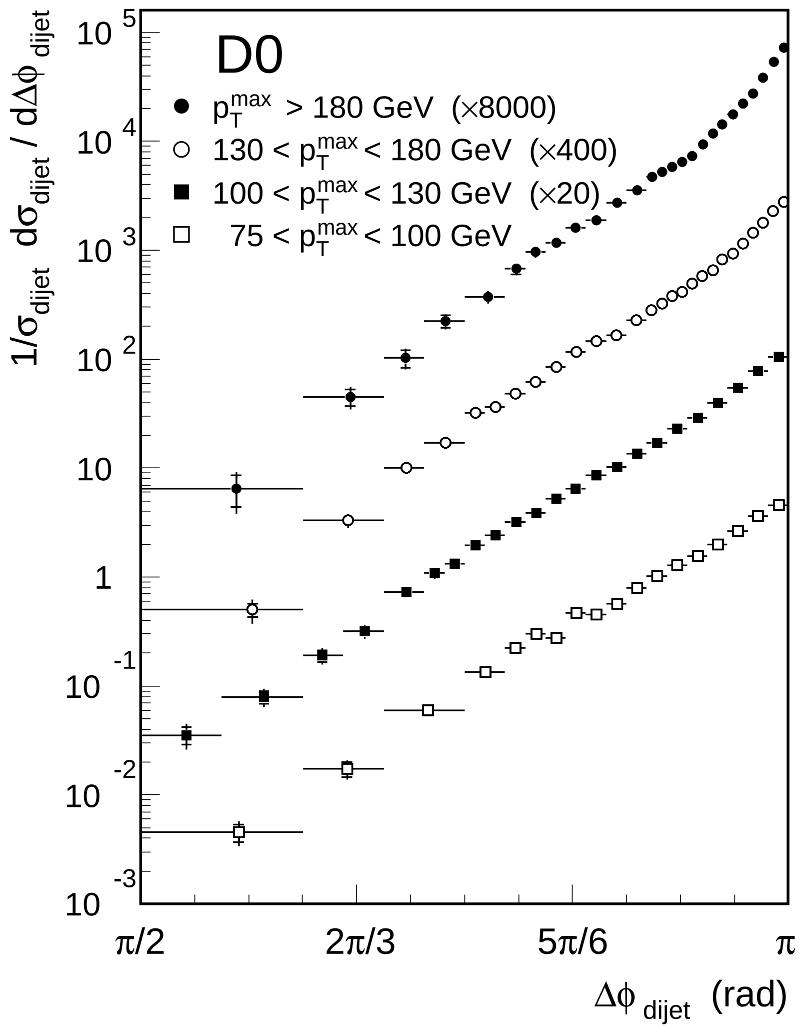
$$Obs = \frac{1}{\sigma_{\text{dijet}}} \cdot \frac{d\sigma_{\text{dijet}}}{d\Delta\Phi}$$

- Advantages:
  - ➔ ΔΦ is a simple variable, uses only the two leading jets
  - ➔ No need to reconstruct or use the softer jets
  - ➔ Jet direction is well measured
  - ➔ Reduced sensitivity to jet energy scale and normalization
  - ➔ Theoretical uncertainties also are reduced in the ratio

- Data sample:
  - ➔ 150 pb^{-1} integrated luminosity
  - ➔ Jets reconstructed with cone algorithm R = 0.7
  - ➔ Require that the two leading jets are central: |y| < 0.5
  - ➔ Second-leading p_T > 40 GeV
  - ➔ Leading jet p_T bin thresholds:
    - ❖ 75, 100, 130, 180 GeV
  - ➔ Quality requirements imposed on running conditions, vertex, jets, and missing ET

- Results published in PRL 94, 221801 (2005)

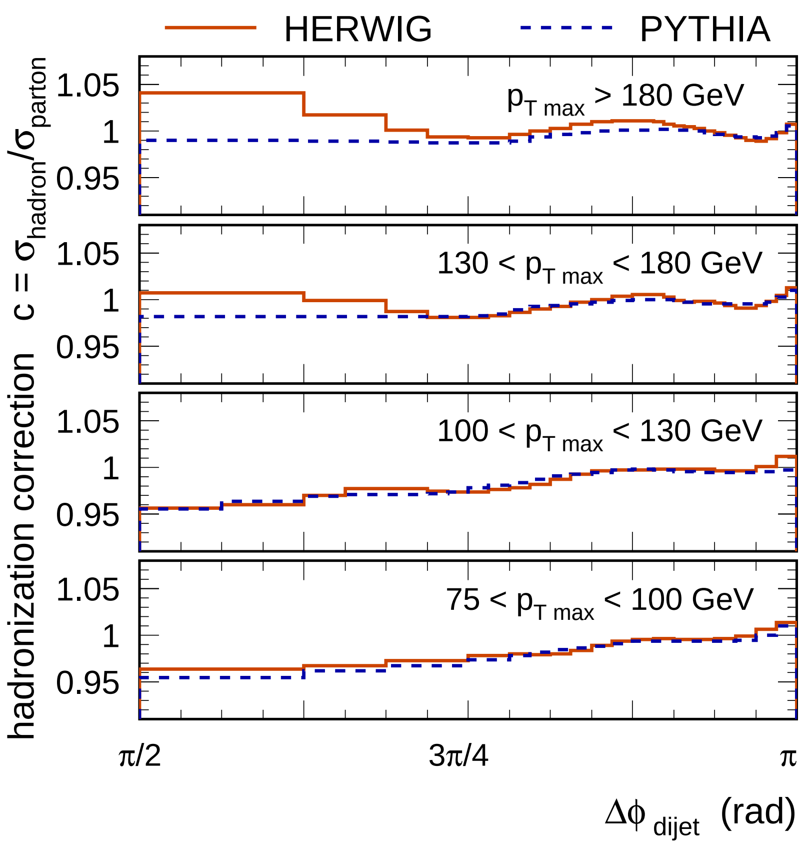
ΔΦ Results



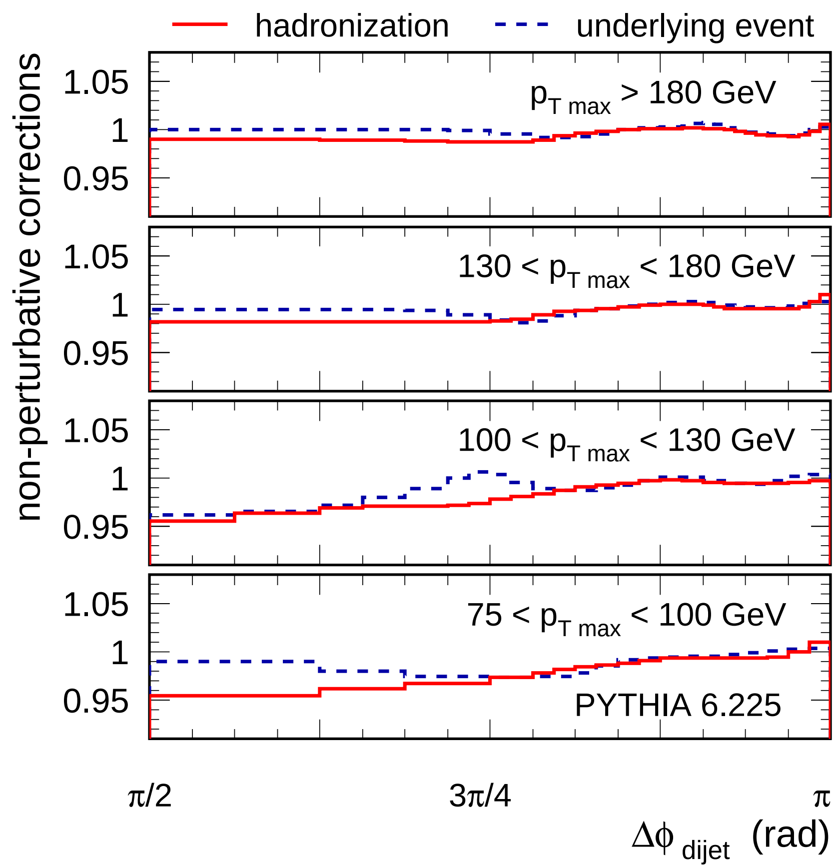
- Data corrected for:
  - ➔ Cut efficiencies
  - ➔ Jet energy scale
  - ➔ Resolution effects (unfolding)
- Dominant systematic uncertainty from jet energy effects
  - ➔ < 7% for $\Delta\Phi \sim \pi$, up to 23% for $\Delta\Phi < 2\pi/3$
- Towards larger p_T, ΔΦ spectra more strongly peaked near π
  - ➔ Increased correlation in ΔΦ
- Distributions extend into the "4 final-state parton regime", $\Delta\Phi < 2\pi/3$
- Data span 4 orders of magnitude across the ΔΦ range
  - ➔ $\pi/2 < \Delta\Phi < \pi$ to avoid jet overlaps

Non-perturbative Effects

Hadronization correction:
Obs(hadron level)/Obs(parton level)

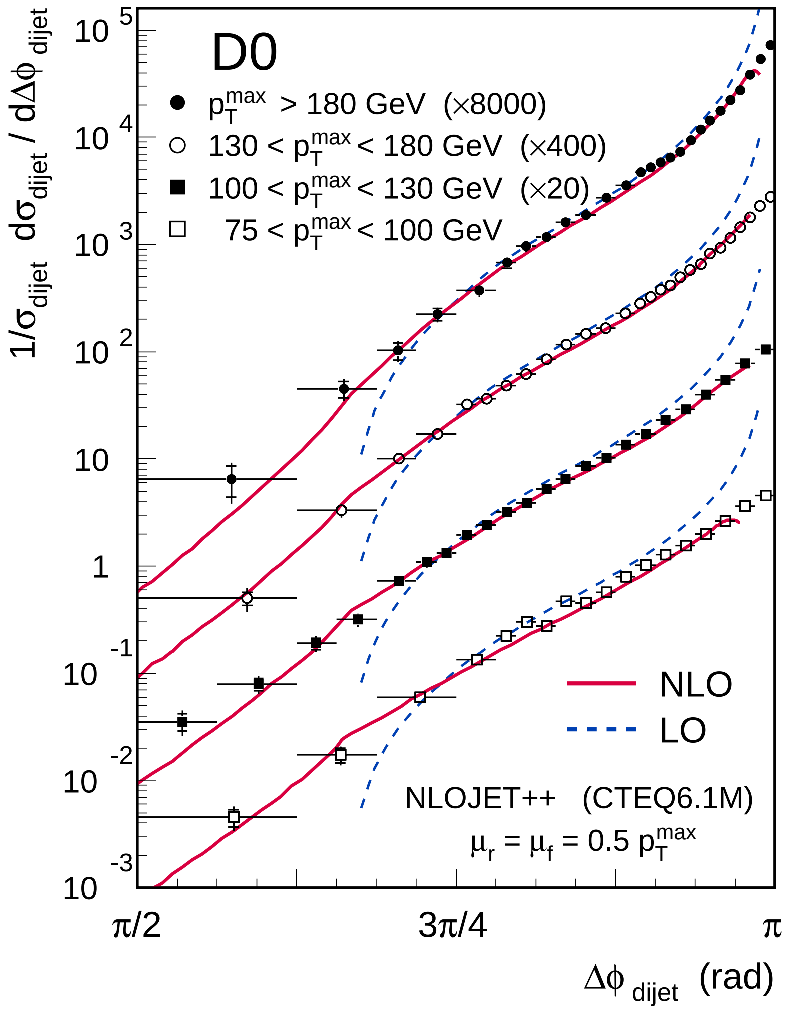


Underlying Event:
Obs(with UE)/Obs(without UE)



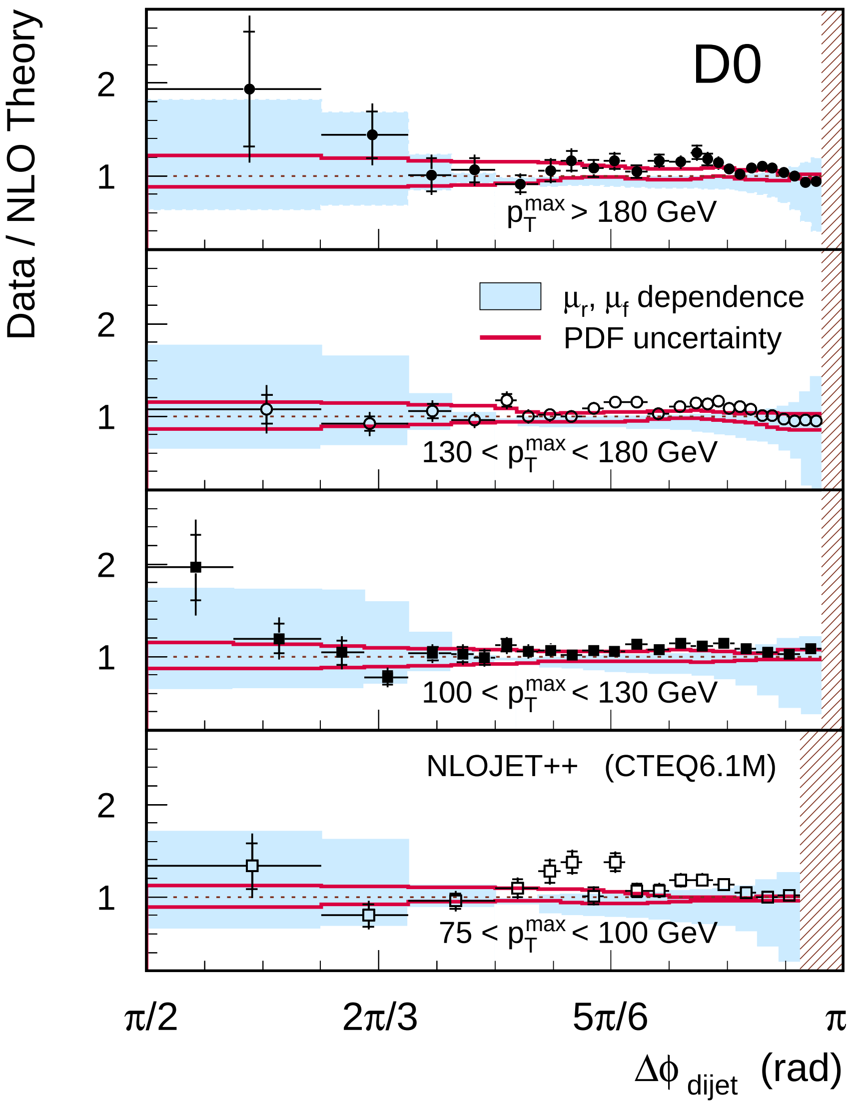
- Non-perturbative effects are < 5% ➔ only sensitive to perturbative aspects

ΔΦ: Comparison to Fixed-Order PQCD



- Leading order (dashed blue curve) – clear limitations
  - ➔ Divergence at $\Delta\Phi = \pi$ (need soft processes)
  - ➔ No phase-space at $\Delta\Phi < 2\pi/3$ (only three partons)
- Next-to-leading order (red curve)
  - ➔ NLOJET++: NLO for 3-jet production ($O(\alpha_s^4)$)
  - ➔ Good description over the whole range, except in extreme ΔΦ regions

Quantitative Comparison: Data and NLO



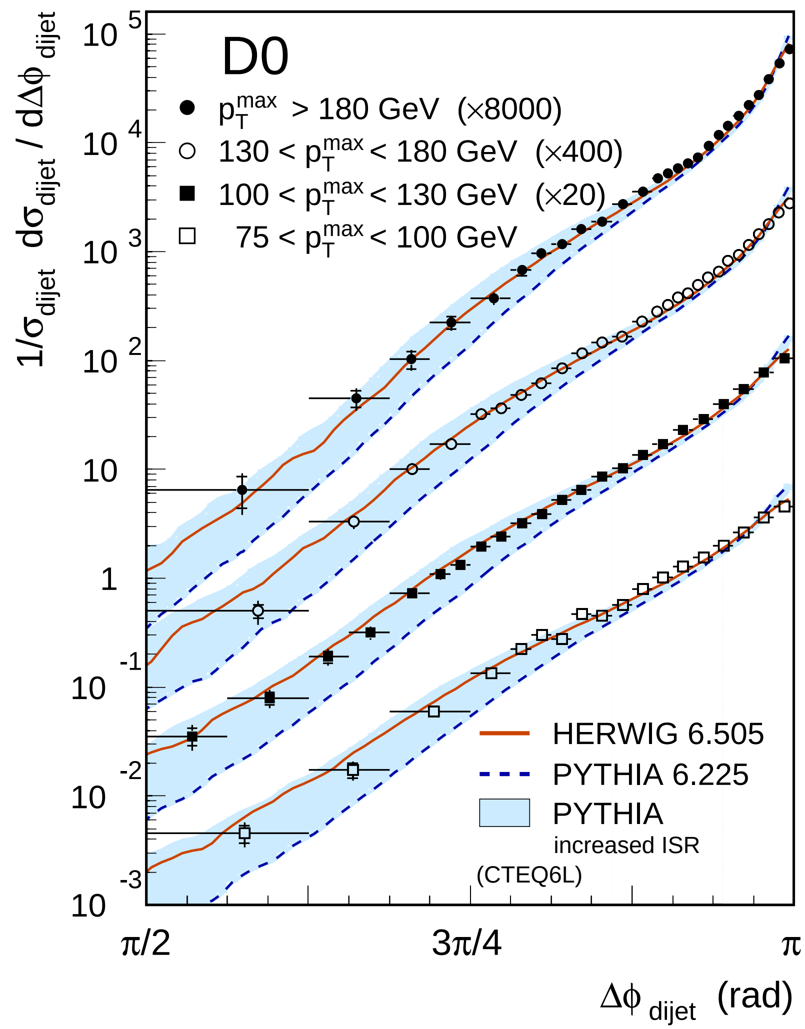
- NLO PQCD
  - ➔ Good overall description: on average 5-10% below data, except for $\Delta\Phi \sim \pi$ (where it needs resummation of soft processes)
- Renormalization and factorization scale dependence: $0.25p_T^{max} < \mu_{r,f} < p_T^{max}$
  - ➔ Small at intermediate $\Delta\Phi$
  - ➔ Large at $\Delta\Phi \sim \pi$ (soft region)
  - ➔ Large at $\Delta\Phi < 2\pi/3$ (tree-level region)
- PDF uncertainty estimated using CTEQ6.1M PDF set
  - ➔ Larger in high p_T^{max} region

ΔΦ: Comparison to Parton-Shower MCs

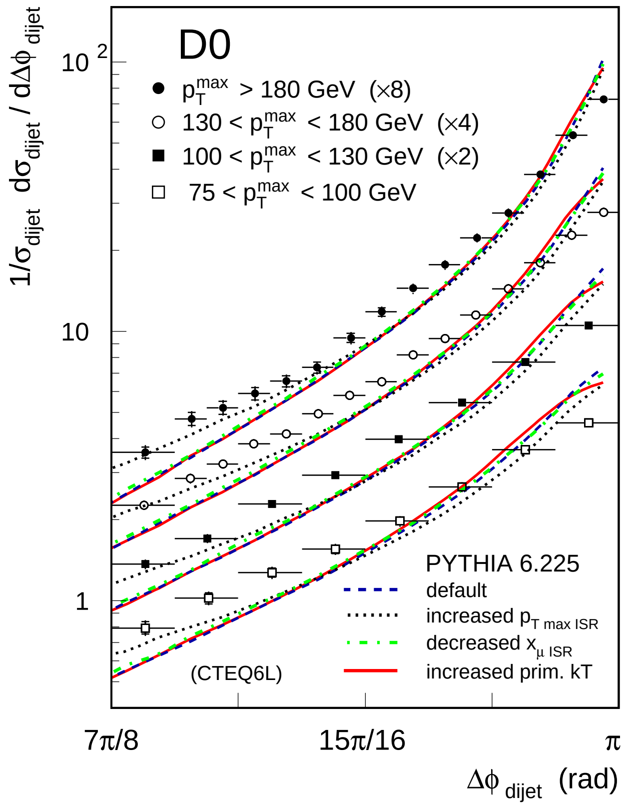
- Testing the radiation process:
  - ➔ 3rd and 4th jets from parton showers
- Herwig
  - ➔ Good overall description
- Pythia
  - ➔ Default (dashed): very different shape
  - ➔ Sensitivity to ISR
    - ❖ Bands: variation of PARP(67) = 1.0-4.0

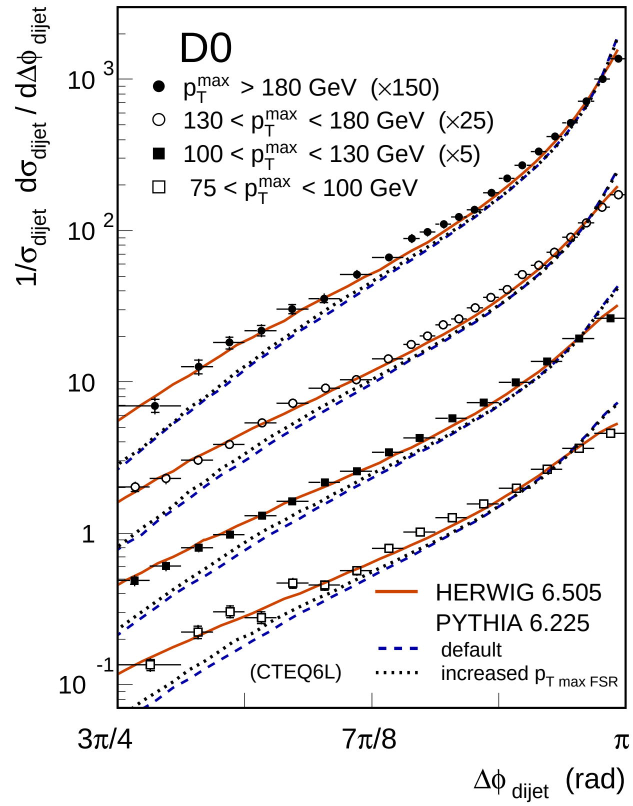
      PARP(67)*hard scale (~p_T) defines maximum virtuality in ISR shower -- directly related to max p_T in the shower
    - ❖ PARP(67) = 2.5 fits well
  - ➔ Not sensitive to soft/FSR params

  - ➔ ΔΦ data provides input to global tuning of Pythia parameters



More Pythia Tuning – Soft Params



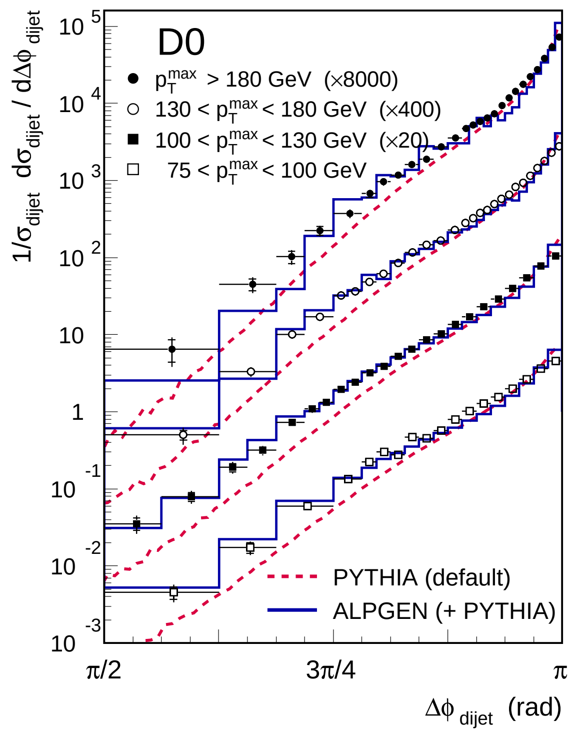


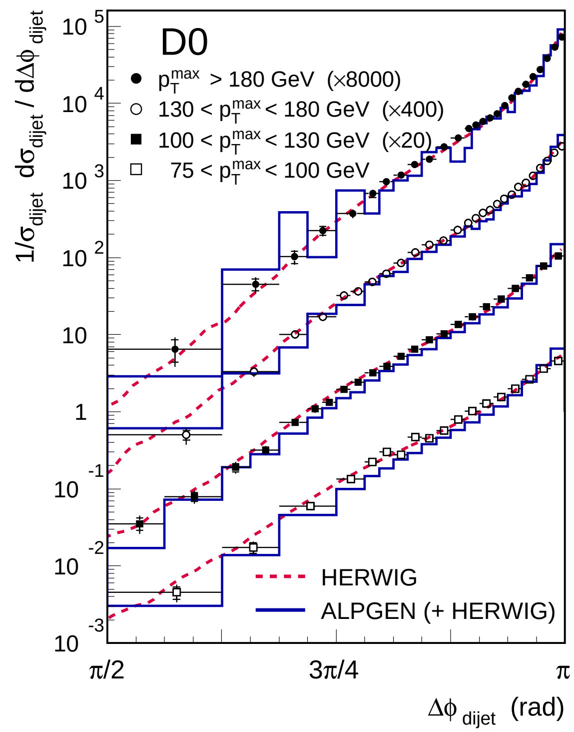
- Description of the $\Delta\Phi \sim \pi$ region not ideal – tried further tuning
  - ➔ $x_{\mu\ ISR}$, PARP(64) = 0.5-1.0
  - ➔ Primordial k_T, PARP(91) = 1.0-4.0 and upper cut-off PARP(93) = 4.0-8.0
  - ➔ $p_{T\ max\ FSR}$, PARP(71) = 4.0-8.0
  - ➔ No sensitivity…

Beyond Pythia and Herwig

- Parton Shower MC's:
  - ➔ Limited to 2→2 hard processes
  - ➔ Resum soft radiation to all orders
  - ➔ Difficult to produce high jet multiplicity events
- Matrix Element generators
  - ➔ Exact for 2→N hard processes (at LO)
- PS-ME matching prescriptions combine strengths of both approaches
  - ➔ Aim at good description of both soft and hard regions
  - ➔ Avoid double counting of equivalent phase space configuration
  - ➔ Alpgen and Sherpa widely used to study processes with multi-jet final states at Tevatron and LHC
- $\Delta\Phi$ can test performance across a range of jet multiplicities

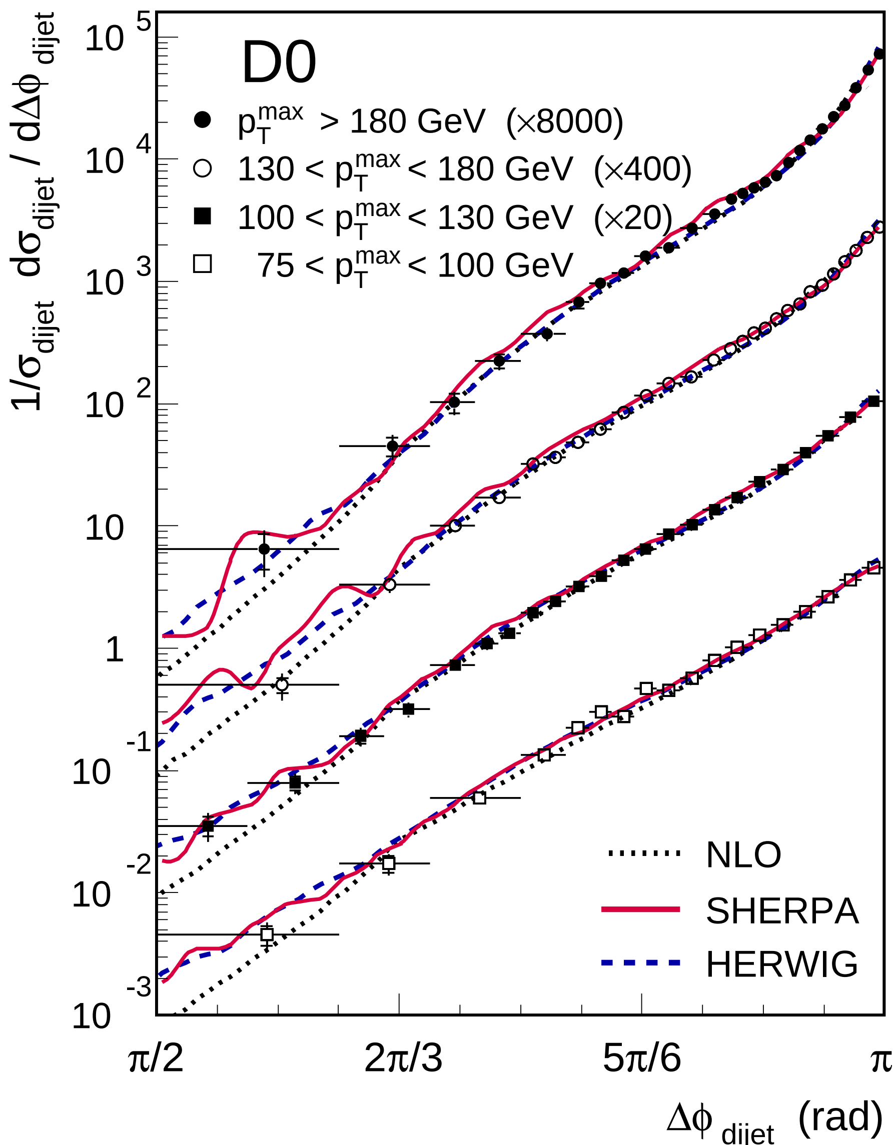
Comparisons to Alpgen





- Alpgen: tree-level production for 2→2, 3, …, 6 jets
  - ➔ Interfaced to both Pythia and Herwig for parton showers and hadronization
  - ➔ Matching via MLM prescription (Mangano)
  - ➔ Alpgen+Pythia and Alpgen+Herwig yield similar results
    - ❖ Details of parton shower model not important
  - ➔ Reasonable description of the $\Delta\Phi$ data

Comparisons to Sherpa



- Sherpa event generation:
  - ➔ Tree-level production of up to 4-parton final states
  - ➔ Implementation of parton showering
  - ➔ Matching via CKKW prescription (Catani, Krauss, Kuhn, Webber)
  - ➔ Hadronization
- Good description of the $\Delta\Phi$ data over the full range of our measurements

Summary

- The ΔΦ distribution has been measured for central jets in four p_T regions using 150 pb^{-1} of DØ Run II data
  - ➔ Sensitive to higher-order QCD processes
  - ➔ Test of 3-jet NLO PQCD at Tevatron
    - ❖ Good agreement for most of ΔΦ range
  - ➔ Helpful for tuning perturbative parameters in parton-shower MC's
    - ❖ Not sensitive to non-perturbative effects (hadronization, underlying event)
    - ❖ Herwig doing well, sensitivity to ISR in Pythia
  - ➔ Test of ME-PS matching schemes for multi-jet configurations
    - ❖ Good description by Alpgen and Sherpa